LLNL-PROC-680604

LAWRENCE LIVERMORE NATIONAL LABORATORY

Debris and Shrapnel Assessments for National Ignition Facility Targets and Diagnostics

N. D. Masters, A. Fisher, D. Kalantar, J. Stolken, C. Smith, R. Vignes, S. Burns, T. Doeppner, A. Kritcher, H. S. Park

January 7, 2016

Inertial Fusion Sciences & Applications
Seattle, WA, United States
September 20, 2015 through September 25, 2015

Debris and Shrapnel Assessments for National Ignition Facility Targets and Diagnostics

N.D. Masters, A. Fisher, D. Kalantar, J. Stölken, C. Smith, R. Vignes, S. Burns, T. Doeppner, A. Kritcher, H.-S. Park

Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

E-mail: `masters6@llnl.gov`

Abstract.

High energy laser experiments at the National Ignition Facility (NIF) have the potential to create debris and shrapnel capable of damaging laser optics and diagnostic instruments [1, 2]. The size, composition, and location of target components and sacrificial shielding (e.g., disposable debris shields, or diagnostic filters) and consequently the protection they provide is constrained by many factors, including: chamber and diagnostic geometries, experimental goals, and material considerations. Therefore an assessment of the generation, nature and velocity of shrapnel and debris and their potential threats is necessary prior to fielding targets or diagnostics. In many cases, these assessments may influence target and shielding design, filter configurations, and diagnostic selection.

This paper will outline the approach used to manage the debris and shrapnel risk associated with NIF targets and diagnostics and and present some aspects of two such cases: the Material Strength Rayleigh-Taylor campaign [3, 4, 5] and the Mono Angle Crystal Spectrometer (MACS) [6].

1. Introduction

High energy laser experiments at the National Ignition Facility (NIF) create debris and shrapnel capable of damaging laser optics and diagnostic instruments [1, 2]. An important aspect of NIF operations, particularly with increased shot rates, is the identification and management of risks to the facility posed by debris and shrapnel. The NIF Debris & Shrapnel Working Group is charged with assessing potential risks: identifying the generation, nature, and velocity of shrapnel and debris and the effect they may have on laser optics and target diagnostics; and recommending strategies for managing these risks.

The formal approach to debris and shrapnel risk management is captured by the Risk Management Flowchart in Fig 1. Hazards are largely due to two sources: 1. Diffuse, consisting mainly of so-called debris wind loads and 2. Local Effects, including shrapnel effects and x-ray ablation. Identification of these hazards for a given experiment may involve previous experience, analytic models, or detailed numerical simulation. The consequences of the identified hazards—potential damage to laser optics and target diagnostics—are then evaluated in terms of severity and probability. Having identified the risks, the appropriate risk reduction strategy can be selected: Avoidance (e.g., modifying the design to minimize risk), Mitigation (applying controls, e.g., changes to diagnostic configuration including additional filtration or using passive detectors, to minimize the impact of risk), or Transferrence (transferring risk to the facility to be accepted).

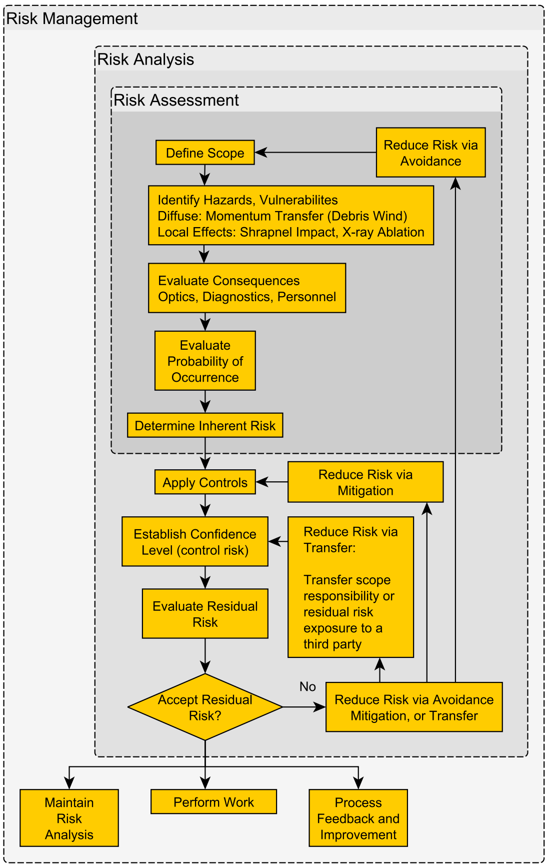

Figure 1. Flowchart of NIF Debris and Shrapnel Risk Management Approach.

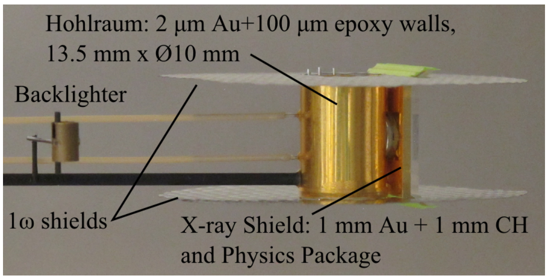

Figure 2. Final Material Strength Rayleigh-Taylor Target design

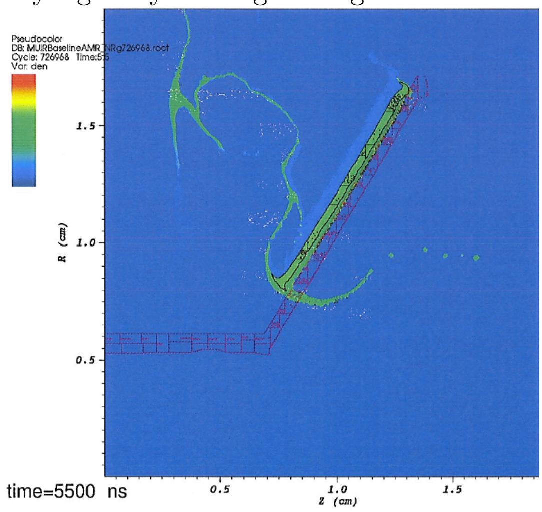

Figure 3. Axisymmetric ARES simulation of large shield MatStrTaRT at 5.5 μs (z-axis is horizontal)

The following case studies present examples of the risk assessment, analysis and management strategies.

2. Case Studies

2.1. Material Strength Tantalum Rayleigh-Taylor (MatStrTaRT)

The MatStrTaRT target is 13 mm $\times$ $\oslash$ 10 mm thin-walled gold-epoxy warm hohlraum (see Fig. 2). The laser pulse (nominally 800 kJ) indirectly drives a tamper and rippled material sample producing Rayleigh-Taylor instabilities which are imaged, face-on, with point projection x-ray backlighter and passive diagnostic and used to develop material strength models at high pressures and strains rates [3, 4, 5]. Background hohlraum emissions are reduced by a flat gold shield 1mm thick covering the full extent of the hohlraum (the physics package is mounted in an aperture in the shield). The shield extends above and below the hohlraum to block LEH emissions with the extensions angled at 30° to avoid interference with drive beams and presenting the same apparent thickness as the main shield (see Fig 2). Dimpled unconverted light shields are also required to mitigate specular reflections of 1ω light from the target that could damage laser components.

The initial design intended to fully shield LEH emissions by extending the shields ≈7.5 mm above and below the LEH. Hydrocode simulations of the large shield design predicted significant amounts of solid and molten debris with sufficient size and velocity to damage several layers of NIF optics (see Fig. 3). In terms of Risk Acceptance, superficial damage to the 3.3 mm disposable debris shields (DDS) may be acceptable, but full penetration and any predicted damage to the 10 mm thick Grated Debris Shields (GDS) or other optics is not. Reducing the size of the aperture on the primary diagnostic allowed lower profile shield extensions to be used. Simulation of the new configuration predicted near full melt of the shield with little directed towards the optics, thus avoiding the risk of the initial design. As such the residual risks could be transferred and accepted by the facility: significant x-ray and debris load on the primary diagnostic and only a nominal debris risk to the laser optics

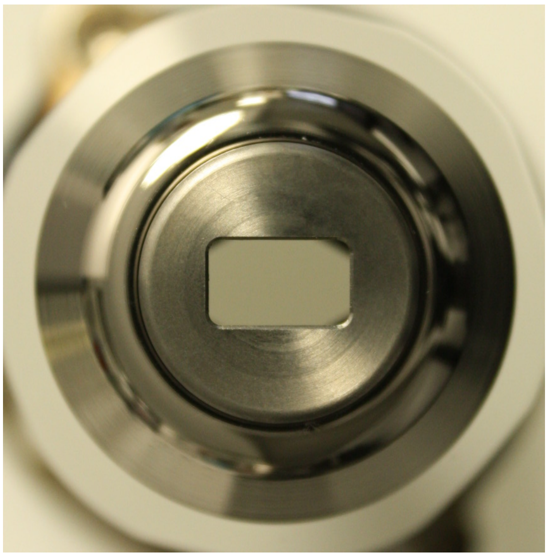

Figure 4. HEIDI nosecap before shot.

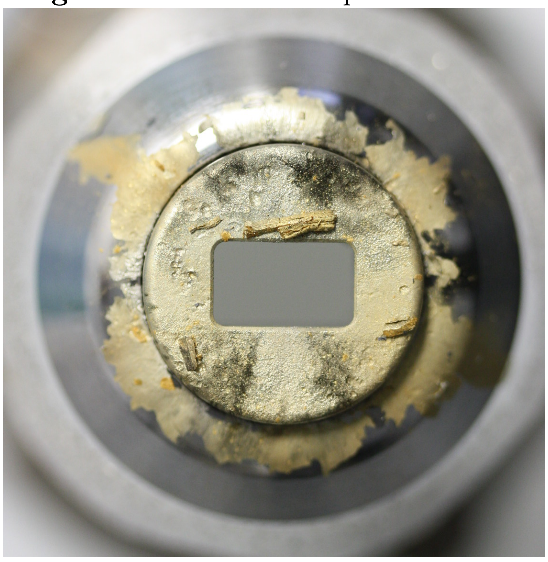

Figure 5. Significant debris deposition following shot, including large gold fragments

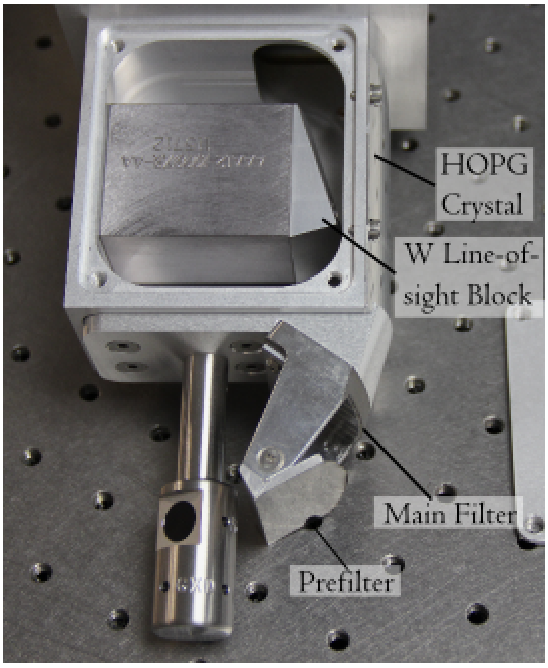

Figure 6. MACS Spectrometer with side panel removed showing line-of-sight block, location of crystals and pre- and main filters

Figure 7. Main filter after shot exhibiting x-ray or plasma affected regions, shadowed regions, and absence of prefilter

Post shot inspections from many MatStrTaRT shots have found no optics damage resulting from these shots. The HEIDI diagnostic does collect significant debris and shows cratering of the tungsten alloy aperture, for example, see pre- and post-shot images of nosecap from N130923, Figures 4 and 5. The strip of gold stuck to the aperture is approximately 7 mm $\times$ 1 mm.

2.2. Mono Angle Crystal Spectrometer (MACS)

The MACS diagnostic has been developed for x-ray Thompson scattering spectroscopy of matter and uses a curved Highly-Oriented Pyrolytic Graphite (HOPG) crystal to focus the x-ray scattering signal towards one strip of a NIF Gated X-ray Detector (GXD) [6].

Although the direct line-of-sight to the detector is blocked (see Fig. 6), the fragile HOPG crystals would be damaged without filtration. X-ray ablation simulations found that monolithic or stacked polycarbonate filter configurations could suffer spall failures and thus would not mitigate the risk. The addition of a thin tilted prefilter has been identified as a successful risk avoidance strategy, decoupling the x-ray and debris loads by allowing the blowoff from x-ray ablation to be directed away from subsequent filters [7]. A 25 μm kapton prefilter was selected (based on predicted ablation depth of 7 μm). The 700 μm main filter is sized to provide a total apparent thickness of < 820 μm. The main filter covers a large aperture and despite x-ray decoupling remains subject to significant debris wind loading. The risk associated with the main filter failing is mitigated by adding muntins to reduce the unsupported spans of the main filter. Post-shot inspections (see Fig. 7) have found that this configuration has performed well.

3. Conclusions

This paper has described some of the influence debris and shrapnel assessments have on the design of NIF targets and diagnostics. Careful assessment of the risks posed by any new target or diagnostic allows the risk to be avoided or mitigated, facilitating the scientific goals while limiting the risk transferred to the facility. The risk reduction steps taken in the development of the MatStrTaRT target and MACS spectrometer demonstrate Avoidance, Mitigation, and Transference strategies.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

References

[1] Eder D, Fisher A, Koniges A and Masters N 2013 *Nuclear Fusion* **53** 113037

[2] Eder D C, Koniges A E, Landen O L, Masters N D, Fisher A C, Jones O S, Suratwala T I and Suter L J 2008 *Journal of Physics: Conference Series* **112** 032023

[3] Park H S, Arsenlis A, Barton N, Benedetti L R, Bolme C, Huntington C M, Genei A E, Lee H J, McNaney J M, McGonegle D, Orlikowski D A, Prisbrey S, Rudd R E, Swift D, Wark J S, Weber S V, Wehrenberg C E and Zepeda-Ruiz L 2015 *IFSA talk*

[4] Park H S, Rudd R E, Cavallo R M, Barton N R, Arsenlis A, Belof J L, Blobaum K J M, El-dasher B S, Florando J N, Huntington C M, Maddox B R, May M J, Plechaty C, Prisbrey S T, Remington B A, Wallace R J, Wehrenberg C E, Wilson M J, Comley A J, Giraldez E, Nikroo A, Farrell M, Randall G and Gray G T 2015 *Physical Review Letters* **114**

[5] Prisbrey S T, Park H S, Remington B A, Cavallo R, May M, Pollaine S M, Rudd R, Maddox B, Comley A, Fried L, Blobaum K, Wallace R, Wilson M, Swift D, Satcher J, Kalantar D, Perry T, Giraldez E, Farrell M and Nikroo A 2012 *Physics of Plasmas* **19** 056311

[6] Döppner T, Kritcher A L, Neumayer P, Kraus D, Bachmann B, Burns S, Falcone R W, Glenzer S H, Hawreliak J, House A, Landen O L, LePape S, Ma T, Pak A and Swift D 2014 *Review of Scientific Instruments* **85** 11D617

[7] Fournier K B, Celeste J, Rekow V, Bopp D R, May M J, Fisher J H, Horton R, Newlander C D, Jenkins P and Trautz K 2010 *Review of Scientific Instruments* **81** 075113